

HIGH-MELTING SUPERALLOY AND METHOD OF PRODUCING THE SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a high-melting superalloy. More specifically, the invention relates to a new high-melting superalloy having an excellent high-temperature strength and a good ductility, which is useful as a material for high-temperature instruments such as a gas turbine for electric power generation, a jet engine, a rocket engine, etc.

2. Description of the Related Art

Turbine blades and turbine vanes used for high-temperature instruments such as a gas turbine for electric power generation, a jet engine, a rocket engine, etc., are used under high-temperature and high-stress conditions. Hitherto, for these turbine blades and turbine vanes, Ni-base superalloys having a high heat resistance and an excellent high-temperature strength have been used but the use temperature have become severe year by year. This is because the increase of a combustion gas temperature is the most effective correspondence to further increase the output and the heat efficiency of high-temperature instruments. Consequently, for the turbine blades and the turbine vanes, the improvement in the high-temperature strength has been

desired, which means, in other words, that the improvement in the high-temperature strength of materials used for turbine blades and turbine vanes is indispensable. The durable temperature of Ni-base superalloys capable of having a substantial strength is about 1,100°C. If a new material, which can be used at a temperature higher than the temperature and can be realized at a relatively low cost, can be developed, it is very useful for practical use.

With respect to Ni-base superalloys having superior high-temperature strength, various investigations have hitherto been made in order to improve an acid resistance, a corrosion resistance, etc. For example, the present inventors have proposed to improve the high-temperature strength and the high-temperature corrosion resistance by solid-solution strengthened Ni-base superalloys in which from 0.1 to 5 atomic % of iridium (Ir) is added, whereby iridium is subjected to solid solution in a γ -phase and a γ' -phase (see Japanese Patent Laid-Open No. 183281/1998).

On the other hand, the present inventors have also already proposed high-melting alloys having two crystal structures, i.e., an FCC structure and an $L1_2$ structure, in which iridium, rhodium or a mixture thereof is added with niobium, tantalum, titanium, aluminum, etc., as alloys having excellent high-temperature strength characteristics and

oxidation resistance characteristics (see Japanese Patent Laid-Open No. 311584/1996).

However, these Ni-base heat-resistant superalloys are lowered in ductility with an improvement in the strength and are troublesome as practically useful heat-resistant materials. Additionally, the prior art iridium-base alloys or rhodium-base alloys are high in cost of the raw materials and involve disadvantages in general-purpose properties. In this sense, the Ni-base superalloys which are relatively cheap and can be easily handled are advantageous.

However, the related art Ni-base heat-resistant superalloys can not be used at the temperature condition of above 1,300°C as a melting point.

SUMMARY OF THE INVENTION

The present invention has been made in view of the circumstances as described above, and the invention relates to a new high-melting superalloy which can further improve the output and the heat efficiency of high-temperature instruments, has the characteristics better in not only high-temperature strength but also ductility than the related art Ni-base superalloys, and can be realized at a relatively low cost.

As a result of various investigations, the present inventors have discovered that by compounding or mixing an

iridium-base alloy (melting point: 2,447°C) or a rhodium-base alloy (melting point: 1,960°C) having a high-melting point and a high strength at a high temperature and being excellent in the oxidation resistance with nickel or a nickel-base alloy (density: 8.9 g/cm³ (cf., density of an iridium-base superalloy: 22.4 g/cm³, density of a rhodium-base superalloy: 12.44 g/cm³)), which is light-weight, is excellent in ductility, and is inexpensive as compared with the above-described superalloys, followed by ingoting, a superalloy wherein both phases of an fcc phase and an LI₂ phase are formed in the texture, and a deposit having an LI₂ structure in the matrix phase having an fcc structure is conformity-deposited is obtained, and that the obtained superalloy is not only excellent in the high-temperature strength and the oxidation resistance but also relatively light-weight and also has a ductility, leading to accomplishment of the present invention.

That is, a first aspect of the present invention is to provide a high-melting superalloy comprising (A) from 5 to 65 atomic % of nickel and (B) from 5 to 20 atomic % of at least one metal selected from the group consisting of titanium, zirconium, hafnium, vanadium, niobium, and tantalum, with (C) from 30 to 75 atomic % of iridium or rhodium, or a mixture thereof, wherein a LI₂ phase is precipitated in a fcc phase

of the matrix phase, and an amount of the LI_2 phase is from 20 to 80% by volume.

Also, a second aspect of the invention is to provide the high-melting superalloy according to the first aspect, wherein an atomic ratio of sum of (A) and (B) is from 20 to 70%.

A third aspect of the invention is to provide the high-melting superalloy according to the first or second aspect, wherein, in case that the metal (c) is iridium, an atomic ratio of (A) to (B) is from 0.3:1 to 8:1.

A fourth aspect of the invention is to provide the high-melting superalloy according to the first or second aspect, wherein, in case that the method (C) is rhodium, the atomic ratio of (A) to (B) is from 0.25:1 to 12:1.

A fifth aspect of the invention is to provide the high-melting superalloy comprising (A) from 4 to 86 atomic % of nickel, (B) from 0.5 to 20 atomic % of at least one metal selected from the group consisting of titanium, zirconium, hafnium, vanadium, niobium, and tantalum, and (C) from 4 to 86 atomic % of iridium or rhodium, or a mixture thereof, with (D) from 0.4 to 20 atomic % of aluminum, wherein a LI_2 phase is precipitated in a fcc phase of the matrix phase, and an amount of the LI_2 phase is from 20 to 80% by volume.

The sixth aspect of the invention is to provide the high-melting superalloy according to fifth aspect, wherein

the sum of atomic % of (A) and (C), and (B) and (D) are set as follows;

$$(A) + (C) \geq 75 \text{ atomic \%}$$

$$(B) + (D) \leq 25 \text{ atomic \%}$$

A seventh aspect of the invention is to provide a method of producing a high-melting superalloy as set forth in any of the first to fourth aspects, which comprises compounding at least one of an iridium-base superalloy made of iridium as a base added with at least one metal selected from the metal group consisting of titanium, zirconium, hafnium, vanadium, niobium, and tantalum and a rhodium-base superalloy made of rhodium as a base added with at least one metal selected from the above-described metal group, with nickel, followed by ingoting to produce a high-melting superalloy.

An eighth aspect of the invention is to provide a method of producing a high-melting superalloy as set forth in any of the first to sixth aspects, which comprises compounding at least one of an iridium-base superalloy made of iridium as a base added with at least one metal selected from the metal group consisting of titanium, zirconium, hafnium, vanadium, niobium, and tantalum and a rhodium-base superalloy made of rhodium as a base added with at least one metal selected from the above-described metal group, with a nickel-base alloy made of nickel as a base added with at least one metal selected from

the above-described metal group, or aluminum, followed by ingoting to produce a high-melting superalloy.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1a, 1b, 1c, and 1d each is an optical microphotograph showing the texture of each sample in Example 1;

Fig. 2 is a bar graph comparing the compression strength and the ductile of each sample in Example 1 with those of Ir-15Nb;

Figs. 3a, 3b, and 3c each is a secondary electron image photograph showing the texture of the Ir-Nb-Ni-Al quaternary alloy in Example 2;

Fig. 4 is a correlation diagram showing the correlation of the ratio of an iridium-base superalloy and the compression strength of the superalloy prepared in Example 2;

Fig. 5 is a correlation diagram showing the correlation of the addition amount of niobium or tantalum in an iridium-base superalloy and the compression strength of the superalloy prepared in Example 2;

Figs. 6a, 6b, 6c, and 6d each is a microphotograph showing the texture of each sample in Example 3;

Fig. 7 is a correlation diagram showing the correlation of the content of nickel in the superalloys prepared in Example 3 to the compression strength and ductile thereof;

Fig. 8 is a view showing the compression strengths and the room-temperature compressive strains of the superalloys of the invention containing Rh and Ir;

Fig. 9 is a photograph showing a fracture surface of the superalloy of the invention; and

Fig. 10 is a photograph showing the texture of the superalloy of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Then, the high-melting superalloy of the invention and the method of producing the same are described in detail.

The high-melting superalloy according to the invention comprises (A) from 5 to 73 atomic % of nickel and (B) from 2 to 22 atomic % of at least one metal selected from the group consisting of titanium, zirconium, hafnium, vanadium, niobium, and tantalum, with (C) a balance of iridium or rhodium, or a mixture thereof, wherein an fcc phase and a LI_2 phase are formed in a texture thereof and the LI_2 phase is precipitated in a fcc phase of the matrix phase, and an amount of the LI_2 phase is from 20 to 80% by volume.

Needless to say, it is acceptable that inevitable impurities mingled in the raw materials during the production or in the production steps are present in this composition.

A proportion of the component (C), i.e., iridium or rhodium, or a mixture thereof, to be contained as a balance is substantially from 30 to 75 atomic %.

In the case where, in the high-melting superalloy of the invention, the components (A), (B) and (C) fall out the above-described composition range, the requirements which are indispensable to the composition of the superalloy of the invention, (1) a LI_2 structure is precipitated in the matrix phase having an fcc structure; and (2) the precipitation phase having an LI_2 structure accounts for from 20 to 80% by volume, cannot be met. Hence, in this case, not only a desired high-temperature strength but also an improvement in the ductility cannot be obtained.

In the invention, in order to attain an excellent high-temperature strength and an improvement in the ductility, it is preferred that a sum of atomic % of (A) and (B) is from 20 to 70% and that, in case of iridium as metal (C), an atomic ratio of the component (A) to the component (B) is from 0.3:1 to 8:1. It is further preferred that, in case of rhodium as metal (C), the atomic ratio of the component (A) to the component (B) is from 0.25:1 to 12:1.

Of titanium, zirconium, hafnium, vanadium, niobium, and tantalum as the component (C) are particularly preferred niobium, tantalum and titanium.

These high-melting superalloys are produced by mixing the alloy-constituting element materials so as to obtain a specified composition, followed by ingoting, and more actually, by compounding at least one of an iridium-base superalloy made of iridium as a base added with at least one metal selected from the metal group consisting of titanium, zirconium, hafnium, vanadium, niobium, and tantalum and a rhodium-base superalloy made of rhodium as a base added with at least one metal selected from the above-described metal group, with nickel, followed by ingoting.

Also, these high-melting superalloys are produced by mixing at least one of an iridium-base superalloy made of iridium as a base added with at least one metal selected from the metal group consisting of titanium, zirconium, hafnium, vanadium, niobium, and tantalum and a rhodium-base superalloy made of rhodium as a base added with at least one metal selected from the above-described metal group, with a nickel-base alloy made of nickel as a base added with at least one metal selected from the above-described metal group, followed by ingoting.

In the invention, aluminum may further be added as the component. In this case, the high-melting superalloy of the present invention comprises

(A) from 4 to 86 atomic % of nickel,

(B) from 0.5 to 20 atomic % of at least one metal selected from the group consisting of Ti, Zr, Hf, V, Nb, and Ta, and

(C) from 4 to 86 atomic % of Ir or Rh, or a mixture thereof,
with

(D) from 0.4 to 20 atomic % of Al.

It is preferred that the sum of atomic % of (A) and (C),
and (B) and (D) are set as follows;

$$(A) + (C) \geq 75 \text{ atomic \%}$$

$$(B) + (D) \leq 25 \text{ atomic \%}$$

In producing the aluminum-containing alloys, nickel-aluminum (Ni-Al) alloys which are presently used as heat resisting materials for high-temperature instruments are useful as the above-described nickel-base alloy.

With respect to the ingoting in the production method, there is no particular restriction regarding the system. For example, there is illustrated a method including an arc-melting of the mixture and a homogenizing treatment, such as heat-treatment at high temperature condition of about 1,800°C and below for homogenizing the composition carried out thereafter as an example.

The high-melting superalloys of this invention produced by these production methods each has both phase of the fcc phase and the LI_2 phase in the texture.

Also, while it is considered that the composition ratio of the metal components on the superalloy is an important factor, a two-phase conformity texture wherein a deposit having an LI_2 structure, is conformity-deposited in the matrix

phase having an fcc structure, is formed. In this case, the two-phase conformity texture means a texture wherein a row of adjacent crystal lattices is continued without being broken. When the two-phase conformity texture is formed, the strength is more increased than the superalloy simply made of two phases of the fcc phase and the LI_2 phase. This is considered to be caused by that the conformity interface between the matrix phase and the deposit disturbs the transfer of the dislocation. Such a two-phase conformity texture is surely formed in the case where at least one of the iridium-base superalloy and the rhodium-base superalloy, and the nickel-base alloy are used as the raw materials in the above-described production method, and each alloy has a two-phase conformity texture having an fcc phase and an LI_2 phase.

It is not always unnecessary that the fcc phase and the LI_2 phase each exists as one kind regarding the kind of constituting substances. Because the high-melting superalloy of the invention is the multi-component alloy as described above, it is possible that plural kinds of the fcc phases and LI_2 phases each having a different existing concentration exist together.

In the texture formed by both phases of the fcc phase and the LI_2 phase, it is preferred that an amount of the LI_2 phase is from 20 to 80% by volume. When the amount of the LI_2 phase

is less than the lower limit, the strength is lowered. On the other hand, the LI_2 phase may exceeds the upper limit but the preparation of such a superalloy becomes considerably difficult.

Also, in the case where the iridium-base superalloy or the rhodium-base superalloy, and nickel or the nickel-base alloy are used as the raw materials, the high-melting superalloy of the invention can independently show the characteristics of the iridium-base superalloy or the rhodium-base superalloy and nickel or the nickel alloy, in the above-described production method. That is, the high-melting superalloy of the invention shows all the high melting point, the high-temperature high strength, and the excellent oxidation resistance of the iridium-base superalloy or the rhodium-base superalloy and also the light-weight and the excellent ductility of nickel or the nickel-base alloy. Also, by the existence of nickel or the nickel-base alloy, the high-melting superalloy of this invention becomes relatively inexpensive.

The high-melting superalloy containing 50 atomic % and below of the iridium-base superalloy or the rhodium-base superalloy of itself or in terms of them is light-weight and is considered to be effective as the rotary members of turbine blades, etc., and on the other hand, when the content of the iridium-base superalloy or the rhodium-base superalloy is

larger than the above-described content, as 50 % and above, the application of the high-melting superalloy of the invention to the members used at a higher temperature is expected to be useful.

Then, the examples of the high-melting superalloy of the invention and the production method thereof are described.

Example 1:

An iridium-15 niobium (Ir-15Nb) alloy was compounded with nickel (Ni) and the mixture was arc-melted in a vacuum furnace under an argon atmosphere to produce four kinds of superalloys (ingots) of A, B, C, and D shown in Table 1 below.

Table 1

| Superalloy | Superalloy Composition (atomic %) | | |
|------------|-----------------------------------|----|---------|
| | Ni | Nb | Ir |
| A | 10 | 15 | Balance |
| B | 20 | 15 | Balance |
| C | 30 | 15 | Balance |
| D | 50 | 15 | Balance |

From each ingot, a test piece having a height of 6 mm and a diameter of 3 mm was cut and subjected to an aging treatment in a vacuum furnace of 5×10^{-7} Torr at 1,300°C for one week. Also, the phase formed in each test piece was determined by an X-ray diffraction analysis (XRD) and an energy dispersion type X-ray analyzer (EDAX).

As a result, the superalloys A and B of Table 1 had the textures composed of only two phases of the fcc phase and the LI_2 phase. In particular, in the superalloy A, a two-phase conformity texture that the precipitation having the LI_2 structure was conformity-precipitated in the matrix phase having the fcc structure was formed. The fcc phase was made of Ir and the LI_2 phase was made of Ir_3Nb . Also, in each of these phases, Ni formed a solid solution with the phase. On the other hand, In the superalloys C and D, in addition to the above-described two phases, a δ phase ($(Ir, Ni)_{11}Nb_9$) belonging to a orthorhombic system was confirmed as a third phase. In addition, in each of the superalloys shown above, an amount of Ir_3Nb having the LI_2 structure was within the range of from 20 to 80% by volume.

Figs. 1a to 1d each is an optical microphotograph of each test piece.

In the superalloy A, a dendrite texture (Fig. 1a) was formed and in the superalloys B, C, and D, fine textures (Figs. 1b, 1c, and 1d) were formed. Also, it was confirmed that with the increase of the compounding amount of Ni, the texture became thicker and rougher.

Also, about the above-described test materials, a compression test (in the air, stress speed $3.0 \times 10^{-4}/s$) was carried out in the temperature range of from room temperature to 1,200°C. The results are shown in the graph of Fig. 2.

As is clear from the graph of Fig. 2, the compression strength of superalloy A was about 2 times that of Ir-15Nb at room temperature and was almost same as that of Ir-15Nb at 1,200°C. The compression strengths of superalloys B, C, and D were lower than the compression strength of Ir-15Nb at both room temperature and 1,200°C. However, the compression strengths of each of the above superalloys are higher than that of an Ni-base superalloy used for high-temperature instruments.

Also, in each of the superalloys, the ductility is improved by the addition of Ni. Particularly, in superalloy B, the ductility is about 13%, which is far higher than that of Ir-15Nb. Also, it is admitted that the utility of the superalloys is higher than the Ir-15Nb alloy. Furthermore, because a part of Ir is replaced with Ni, the Ir amount of the superalloys can be reduced, which lowers the cost of the alloys. Thus, in the point, the high utility of the superalloys is also confirmed.

Example 2:

As the iridium-base superalloy, an iridium-20 niobium (Ir-20Nb) alloy and an iridium-20 tantalum (Ir-20Ta) alloy were selected and, as the nickel-base alloy, a nickel-16.8 aluminum (Ni-16.8Al) alloy was selected. The mol fractions of the iridium-base superalloy and the nickel-base alloy were

selected to be Ir-base superalloy : Ni-base alloy = 25 : 75 (group A), 50 : 50 (group B), and 75 : 25 (group C), sum total 6 kinds of the quaternary alloys of the compositions shown in Table 2 below were prepared by arc-melting in an argon atmosphere.

Table 2

| | Superalloy Composition (atomic %) | |
|---------|-----------------------------------|-------------------------|
| | Ir-5Nb-62.4Ni-12.6Al | Ir-3.75Ta-62.4Ni-12.6Al |
| Group A | Ir-10Nb-41.6Ni-8.4Al | Ir-7.5Ta-41.6Ni-8.4Al |
| Group B | Ir-15Nb-20.8Ni-4.2Al | Ir-11.25Ta-20.8Ni-4.2Al |
| Group C | | |

About these 6 kinds of the quaternary alloys, the phase determination and the texture observation as in Example 1 were carried out.

As a result, in the 4 kinds of the superalloys of group A and group C, the two-phase conformity textures composed of the fcc phase ((Ir, Ni)) and 2 kinds of LI_2 phases ((Ni, Ir)₃ (Al, Ir) and (Ir, Ni)₃ (Nb, Al), or (Ni, Ir)₃ (Ni, Ta) and (Ir, Ni)₃ (Ta, Al)) were formed. On the other hand, in the 2 kinds of the superalloys of group B, the two-phase conformity textures by the fcc phase and 2 kinds of the LI_2 phases same as those of the superalloys of group A and group C were formed but in the cases, B2 phase ((Ir, Ni) (Al, Nb) or (Ir, Ni) (Al, Ta)) was additionally observed.

In addition, in the above-described composition formulae, for example, $(\text{Ni}, \text{Ir})_3 (\text{Al}, \text{Nb})$ means Ni_3Al containing Ir and Nb, wherein a part of Ni is replaced with Ir and a part of Al is replaced with Nb. Other composition formulae also employ the same expression system as above.

Figs. 3a, 3b, and 3c are the secondary electron images showing the textures of Ir-Nb-Ni-Al superalloys belonging to group A, group B, and group C, respectively.

In the superalloy A, the fcc phase and the first LI_2 phase of Ni_3Al containing Ir and Nb were observed. In the superalloys B and C, larger LI_2 phases were deposited. The B2 phase was observed in the superalloy B only as described above. In three superalloys A to C, together with the first LI_2 phase of Ni_3Al containing Ir and Nb, a small second LI_2 phase of Ir_3Nb containing Ni and Al was found in the fcc matrix phase.

Then, the alloys prepared were subjected to an aging treatment in vacuo at 1,300°C and 1,400°C for one week and the textures were observed again.

In each superalloy subjected to the aging treatment of 1,300°C, 2 kinds of small second LI_2 phases were precipitated from the fcc matrix phase. As the result of the phase analysis of the superalloys B and C, it was confirmed that the second LI_2 phase contained larger amount of Ni than the first LI_2 phase. In the superalloy A, 23 atomic % Ir was contained in the first LI_2 phase. The Ir amount in the matrix phase

increased with the increase of the Ir amount of the superalloy. On the other hand, the Nb amount in the matrix phase is almost the level of 5 atomic %. After the aging treatment at 1,400°C, in addition to a larger first LI₂ phase, a large amount of second LI₂ phases each having a different form and size were formed in the fcc phase. Also, in the superalloy B, the B2 phase was vanished. Thus, it is considered that the melting point of the B2 phase in the superalloy B is 1,400°C. Also, in each of the superalloys, an amount of the LI₂ phase was within the range of from 20 to 80% by volume ratio.

The above-described texture observation results were the same as those about the Ir-Ta-Ni-Al quaternary alloy.

Then, each of the following 6 kinds of the quaternary alloys was heated to 1,400°C for one week, and the compression strength of each of them at 1,200°C was measured. The results are shown as the correlation diagrams of Fig. 4 and Fig. 5.

In theses Fig. 4 and Fig 5, for comparison, the strengths of an Ni-base superalloy (Marm 247) and the iridium-base superalloys of Ir-15Nb and Ir-20Nb are shown together.

Each of the quaternary alloys shows the high compression resistance as compared with an Ni-base superalloy applied to high-temperature instruments. On the other hand, the compression strengths of these quaternary alloys are lower than that of Ir-Nb. However, the ductility of each alloy is, by mixing of the nickel-base alloy, 18% at the lowest and is

improved as 89% is obtained at the highest. Thus, it is admitted that the utility of the alloys is higher than Ir-15Nb.

Also, from Fig. 4, it is confirmed that the compression strength of the quaternary alloy is more improved with the increase of the addition amount of Nb or Ta which is the addition component of the indium-base superalloy.

Example 3:

Four samples having the compositions of $\text{Rh}_{85-x}\text{Nb}_{15}\text{Ni}_x$ ($x = 10, 20, 30, \text{ and } 50$) were prepared by arc-melting and from each ingot, a test piece of a height of 6 mm and a diameter of 3 mm was cut. The test piece was subjected to an aging treatment in vacuo ($< 10^{-5}$ Pa) at $1,200^\circ\text{C}$ for 100 hours. Also, a compression test (in the air, stress speed $3.0 \times 10^{-4} \text{ s}^{-1}$) was carried out at a temperature of from 20 to $1,200^\circ\text{C}$. Each test piece was heated to the test temperature for from 12 to 20 minutes in a furnace so that a uniform temperature distribution was obtained during the test and kept at the temperature for 5 minutes before the initiation of loading. The compression strength was calculated from the change of the height of each test piece before and after the test.

Also, the texture of each superalloy was observed by a scanning electron microscope (SEM) and a transmission electron microscope (TEM). The test piece observed by the

scanning electron microscope was electron-polished with an ethyl alcohol solution of 5% HCl. The crystal structures and the phase compositions of the superalloys after the heat treatment were determined by an X-ray diffraction analysis (XRD) and an energy dispersion type X-ray analyzer (EDAX).

Each of the superalloys of $\text{Rh}_{85-x}\text{Nb}_{15}\text{Ni}_x$ of $x \leq 30$ had the texture composed of only 2 phases of the fcc phase and the LI_2 phase of Rh_3Nb containing Ni. Particularly, in the $\text{Rh}_{75}\text{Nb}_{15}\text{Ni}_{10}$ superalloy of $x = 10$, a two-phase conformity texture that a deposit having the LI_2 structure was conformity-deposited in the matrix phase having the fcc structure was formed. On the other hand, in the $\text{Rh}_{35}\text{Nb}_{15}\text{Ni}_{50}$ superalloy of $x = 50$, a γ phase ($(\text{Ni}, \text{Rh})_3\text{Nb}$) belonging to an orthorhombic system was confirmed. The contents of Ni contained in Rh_3Nb were from 48 atomic % of $\text{Rh}_{75}\text{Nb}_{15}\text{Ni}_{10}$ ($x = 10$) to 19.6 atomic % of $\text{Rh}_{35}\text{Nb}_{15}\text{Ni}_{50}$ ($x = 50$). Also, in each superalloy, an amount of the LI_2 phase precipitated in fcc matrix phase was within the range of from 20 to 80% by volume.

Fig. 6 is the microphotographs of the superalloys heat-treated for 100 hours at $1,200^\circ\text{C}$.

Figs. 6a to 6d correspond to the compositions of $\text{Rh}_{85-x}\text{Nb}_{15}\text{Ni}_x$ ($x = 10, 20, 30$, and 50), respectively, and, in each of the superalloys, a dendrite texture is formed. From the comparison of Figs. 6a to 6d, it is confirmed that with

increase of the compounding amount of Ni, the texture becomes coarser as in Example 1.

Fig. 7 is a correlation diagram showing the compression strength and the ductility of the $Rh_{85-x}Nb_{15}Ni_x$ superalloys in the relation of the content of nickel. In Fig. 7, the data of the Rh-15 atomic % Nb alloy are shown together for comparison.

At room temperature, each of the superalloys with Ni added shows a high compression strength as compared with the Rh-Nb two-phase alloy. At 1,200°C, the compression strength of $Rh_{75}Nb_{15}Ni_{10}$ ($x = 10$) is 473 MPa, which is higher than the compression strength of the Rh-Nb two-phase alloy but the compression strength lowers with the increase of the content of Ni. However, the compression strength of each of the superalloys is higher than that of Ni-base superalloys which have hitherto been applied to high-temperature instruments.

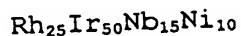
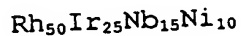
About the ductility at room temperature, the superalloys with Ni added are equal to that of the Rh-Nb two-phase alloy in the composition on $Rh_{55}Nb_{15}Ni_{30}$ ($x = 30$) but the superalloys having other compositions show lower values. However, the ductility of the superalloys is 11% ($Rh_{75}Nb_{15}Ni_{10}$ ($x = 10$)) at the lowest and have the room-temperature ductility higher than those of the In-base superalloys shown in Example 1.

Example 4:

By following the same procedure as Example 2 except that rhodium was used as the component of constituting the superalloys in place of iridium, superalloys were prepared. The compression strength and the ductility of each superalloy were measured together with the determination of each phase and the observation of each texture. Each of the superalloys obtained shows a high compression strength and an improved ductility almost the same as those of Example 2 using iridium, as compared with the Ni-base superalloys which have hitherto been used for high-temperature instruments.

Example 5:

By following the same procedure as in Example 1, the alloys of the following 2 kinds of compositions (atomic %) were produced.



About the 2 kinds of the alloys, the compression strengths (at room temperature and at 1,200°C) and the room-temperature compressive strain were measured, they were compared with those of the high-temperature superalloys of $\text{Rh}_{75}\text{Nb}_{15}\text{Ni}_{10}$ and $\text{Ir}_{75}\text{Nb}_{15}\text{Ni}_{10}$ and also those of the alloy of Ir-Nb₁₅ of related art, and the results are shown in Fig. 8.

From Fig. 8, it can be seen that in the superalloys of this invention containing both Rh and Ir, at room temperature,

the compression strength is about 2 times that of the binary alloy of Ir-Nb₁₅, at 1,200°C, the compression strength is almost same as that of the binary alloy, that is, the high-temperature compression strength is not lowered. Also, it can be seen that the room-temperature compressive strain is more improved as the amount of Rh becomes larger.

Fig. 9 and Fig. 10 are the photographs observing the rupture cross-sections of the alloys and the photographs showing the alloy textures of them, and the alloys are as follows:

- a: Rh₇₅Nb₁₅Ni₁₀
- b: Rh₅₀Ir₂₅Nb₁₅Ni₁₀
- c: Rh₂₅Ir₅₀Nb₁₅Ni₁₀
- d: Ir₇₅Nb₁₅Ni₁₀

From Fig 9, it was confirmed that each alloy showed a transgranular rupture and improved the brittle property of the Ir-Nb binary alloy caused by an intergranular rupture.

From Fig. 10, it was confirmed that in each case, a third phase was not formed and the texture of each alloy was a two-phase texture of fcc + LI₂.

As a matter of course, the invention is not limited to the above-described examples. That is, about the compositions, the compounding ratios, the preparation methods, etc., of the superalloys, various modifications are possible.

As described above in detail, according to the present invention, new high-melting superalloys which have the characteristics better than Ni-base superalloys in related art and can be realized at a relatively low cost are provided. Also, by the invention, the more improvements in the output and the heat efficiency of high-temperature instruments can be realized.